

Northumbria Research Link

Citation: Valinejad, Jaber, Marzband, Mousa, Busawon, Krishna, Kyyra, Jorma and Pouresmaeil, Edris (2018) Investigating Wind Generation Investment Indices in Multi-Stage Planning. In: 5th International Symposium on Environment Friendly Energies and Applications, 24-26 September 2018, Rome.

URL:

This version was downloaded from Northumbria Research Link:
<http://nrl.northumbria.ac.uk/id/eprint/37774/>

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: <http://nrl.northumbria.ac.uk/policies.html>

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)



**Northumbria
University**
NEWCASTLE



UniversityLibrary

Investigating Wind Generation Investment Indices in Multi-Stage Planning

Jaber Valinejad
Bradley Dep. of Electrical
and Computer Engineering
Virginia Tech, Falls
Church, USA
JaberValinejad@vt.edu

Mousa Marzband and Krishna Busawon
Dep. of Physics and Electrical Engineering,
Northumbria University Newcastle
Newcastle, UK
mousa.marzband@northumbria.ac.uk
krishna.busawon@northumbria.ac.uk

Jorma Kyrylä and Edris Pouresmaeil
Dep. of Electrical Engineering
and Automation, Aalto
University, Espoo, Finland
jorma.kyryla@aalto.fi
edris.pouresmaeil@aalto.fi

Abstract— This paper presents a Multi-stage stochastic bi-level model for the expansion planning of Wind resources in power systems at a multi-stage horizon. In this paper, the power system consists of a combination of fossil fuel technologies and Wind resources for investment. Demand is characterized by a certain number of demand blocks. The uncertainty of demand for each this block (for each time period of the curve) is determined by the scenario. Afterwards, the suggested model is converted to a mathematical programming with some equilibrium constraints. Following that, after linearization, a mixed integer linear program is obtained. This framework is examined on the IEEE RTS 24-bus network. The obtained simulation results confirm that this model can be appropriately used as a means to analyze the behavior of investments in wind and thermal units.

Keywords— *capacity investment; power market; wind; dynamic planning; stochastic approach.*

I. INTRODUCTION

The wind power expansion planning has been proposed in recent years. The use of new resources is inevitable because of energy growing and reduction in fossil resources. Today's, wind power sources as one of the main source of electricity in many countries is an alternative to conventional fossil power plants. The consideration of the effects of wind power on the network is important in the development of power system planning studies resulting from penetration of wind power in the power system and an increase in uncertainties [1-2]. Also, supply Security is the most important feature of power system operation which should be considered at different time intervals to be a balance between production and consumption in the long-term [3-4]. In traditional systems, the objective is to minimize the costs associated with the construction of the units with ISO. But, in restructured power systems, each investor will participate as a player in the market [5-7]. The objective function of each of these players is to maximize the benefits from the investments. It is worth noting that the results obtained from these optimizations must consider the limitations of the independent system operator. The following points the important research that has been done in this field:

Ref. [8] suggested a Benders decomposition algorithm to overcome the wind unit investment issues efficiently. In [9], two different methodologies are proposed to consider different scenarios between the electric load and wind power. These scenarios are used as the input information for the issues

associated with the generation expansion. These methodologies encompass the duration curves of load and wind, and the K-means clustering method so that allow representing the uncertainty of and the correlation between the load and production of wind-power. Reference [10] present a model to investigate the impact on market revenue of, respectively, the predictability and the capacity factor of a wind farm or a cluster of wind farms. Financial analysis of a project is provided in reference [11] based on Monte Carlo simulation to present results from decision making process of a model of a representative wind power investor's. Based on the above-mentioned issues, ref. [12] presents a risk-constrained multi-stage stochastic plan to investigate the optimal investment decisions on the wind power units. To model the expansion planning problem considering peak and base technology, [13] propose a stochastic dynamic three level model. A hybrid DP/GAME framework is proposed in [14] to take care of the generation expansion planning (GEP) problem. In this paper, DP was represented to tackle the problem due to the investment, whilst the Cournot model was presented to consider the strategic behavior of producers in the spot markets. In [15], energy efficiency resources are considered as efficiency power plants (EPP) to investigate their impacts on generation investment. The supply curve of EPP is presented by means of the production function of electricity consumption. A decision making model is also expressed to encompass EPP in generation expansion issue from an investor's perspective. In [16], impacts of various uncertainties including forecasting errors of wind power on power generation scheduling are studied. In [17], the role of units and lines failures and correlation of wind power on generation investment issues are investigated. Hence, bi level stochastic optimization problem is proposed. In the aforementioned framework, the sequential and non-cooperative game between producers and the system operator is modeled. A stochastic framework is proposed in ref. [18] for the generation expansion of deregulated power systems in a multi-period horizon, which encompasses generation investment from a strategic producer point of view. The investment issue is presented as a bi-level model. Reference [19] provides a robust optimization method for expansion planning in a transmission network. In this model, uncertainties are related to renewable generation and load. The proposed approach contrasts with conventional stochastic programming in regard to necessary knowledge of the probability distribution of the uncertain net injections. Whilst the uncertainties of the

net injections are expressed by an ordinary uncertainty set. A main concern of governments as regards renewable energy includes renewable electricity policies as well as how to combine them so as to enhance the extension of renewable energy technologies cost-effectively. These issues are examined in [20]; consequently, a financial framework is presented so that feed-in tariffs are combined with investment subsidies as well as soft loans. Optimal government policy is investigated in reference [21] when private investment produces information. In reference [21], it is shown that if the investment subsidy is supported by a non-distortionary, lump-sum tax, the government obtain its favorable offspring.

In this paper, the investment in wind power plants is expressed by considering the components of uncertainty and of the power market by dynamic stochastic MPEC model. The purpose of this paper is to maximize the profit from the investment in wind units (WU) as well as base and peak units(BPU) in a specified period of 10 years. The second level problem is convex; Therefore, the problem can be solved by optimization methods. In the proposed model, the power system is assumed to have WU and BPU so that limitation of the transmission network is considered. The unit technologies for investment are different kinds of WU and BPU so that uncertainties related to the generating of WU and consumers are considered in this network.

The paper is presented as follows. The mathematical formulation of the problem is presented in Section ‘Mathematical formulation’. Subsequently, information of case study which is IEEE 24-bus Reliability Test System as well as simulation results are provided in the section ‘Case studies’. Finally, Section ‘Conclusion’ provides some relevant conclusions.

II. MATHEMATICAL FORMULATION

In the following section, the mathematical formulation of this paper is presented. In this model, w as index for scenario, y/y' as indexes for year, t as index for demand blocks, i as index for existing generation unit, s as index for new BPU, j as index for load, h as index for capacity of investment option, and n/m as indexes for bus are considered.

A. The Dynamic stochastic bi-level model for wind investment

The first level shows an investment problem of conventional producers with a view to maximize the present value of the total profit of investment (whether BPU or WU). Due to the fact that the proposed model is multi stage, dynamic constraints are presented in the first level. The second level problem is to model spot market where the priority is to maximize the social welfare. In this model, maximizing the social welfare as objective function of second level problem is equivalent to minimizing the generation cost. DC power flow equations, in addition to the limitation of units’ production are envisaged as constraints of second level problem. Furthermore, market clearing prices as well as units’ production as outputs of the second level problem are fed back to first level one. It is worth mentioning that market clearing

prices are equivalent to dual variables related to the power balance constraints.

$$\begin{aligned} \text{Minimize } & \sum_y \left(\frac{1}{1+f} \right)^y \sum_s k_s^{TH} X_s^{TH} + \sum_y \left(\frac{1}{1+f} \right)^y \sum_t (1-S) c_n^{inv} X_{yn}^W \\ & - \sum_y \left(\frac{1}{1+f} \right)^y \sum_t N_t^h \sum_w \gamma_{tw} \left[\begin{aligned} & \sum_n P_{n,tw}^W \lambda_{ntw} + \sum_n \sum_{y'} P_{yy',n,tw}^{WY} \lambda_{ntw} \\ & + \sum_s P_{Sb,tw}^{TH} \lambda_{ntw} - \sum_s P_{Sb,tw}^{TH} CS_{Sb}^{TH} \\ & \sum_s \sum_{y'} P_{yy',stw}^{THY} \lambda_{ntw} - \sum_s \sum_{y'} P_{yy',stw}^{THY} CS_{Syy'}^{THY} \\ & \sum_i P_{yitw}^{ES} \lambda_{ntw} - \sum_i P_{yitw}^{ES} CS_i^{ES} \end{aligned} \right] \end{aligned}$$

The objective function (1) includes expected revenue offset by investment cost so that it means the present value of the minus expected profit in the planning horizon. This objective function includes three terms. The first and second term of profit function (1) is associated to the investment cost of new BPU and WU, respectively. The third term of profit function (1) is the expected profit earned by selling power in the market clearing. In this constraint, F and S are Discount rate and Subsidy percent, respectively.

k_s^{TH} is Annual investment cost of installed unit (€/MW). X_{sh}^{TH} is Option h for investment capacity of new BPU i (MW). N_t^h is Weight of demand block t in year y . γ_{tw} is Weight of scenario w in demand block t . c_n^{inv} is Investment cost of wind power at bus n . X_{yn}^W is Wind power constructed at bus n . P_{yitw}^{ES} is Power produced by existing unit i (MW). P_{ystw}^{TH} is Power produced by new BPU s . P_{yntw}^W is Wind power produced at bus n . $P_{yy',stw}^{THY}$ is Power produced by new thermal unit s , in year y' . In the years after the installation in year y (MW). CS_s^{TH} is Price offered by new BPU (€/MWh). CS_i^{ES} is Price offered by the existing unit producer. $CS_{Syy'}^{THY}$ is Price offered by new BPU s , in year y' . In the years after the installation in year y . λ_{ntw} is market price.

$$X_{yn}^W = \sum_L u_{ynl}^W X_{nl}^W, \sum_L u_{ynl}^W = 1 \quad u_{ynl}^W \in \{0,1\} \quad (2)$$

Constraint (2) means wind power investment is available only in discrete blocks. According to (2), just one capacity of wind units must be constructed at each bus of the power network for each year in multi stage planning.

$$0 \leq \sum_y X_{yn}^W \leq X_n^{W \max} \quad (3)$$

Constraint (3) Defines maximum capacity of wind units along a multi-stage horizon that can be constructed in each location with wind power facilities.

$$X_{yy',n}^{WY} = X_{yn}^W \quad \forall y, y' \in \{X_{yn}^W > 0, y > y'\} \quad (4)$$

Due to the fact that this model is kind of multi stage, dynamic dependency constraints on decision variables

associated with the wind investment must be considered. This conception is represented in constraint (4). According to this constraint, constructed units are assumed as existing units in the upcoming years.

$$P_{yn,tw}^W \leq K_{n,tw} X_{yn}^W \quad (5)$$

Constraint (5) imposes that wind production at any operating condition is limited to the constructed wind unit at the related bus multiplied by a factor which presents the wind unit intensity at that bus and scenario.

$$X_{ys}^{TH} = \sum_h u_{ysh}^{TH} X_{ysh}^{TH}, \sum_h u_{ysh}^{TH} = 1; u_{ysh}^{TH} \in \{0,1\} \quad (6)$$

Constraint (6) defines that investment capacities for new BPU are only accessible in discrete blocks.

$$X_{yy's}^{TH} = X_{ys}^{TH} \quad \forall y, y' \subset \{X_{y's}^{TH} > 0, y > y'\} \quad (7)$$

Dynamic constraints on decision variables related to the thermal units are represented in constraint (7).

$$\sum_y \left(\frac{1}{1+f} \right)^y \left(\sum_n (1-S) C_n^{inv} X_n^W + \sum_s k_s^{TH} X_{ys}^{TH} \right) \leq K^{\max} \quad (8)$$

Available budget limitation represented in (8) for investment in WU and new BPU. $C_n^{invyear}$ is annualized investment cost of wind unit at bus n.

$$CS_{Syy'}^{TH} = CS_S^{TH} \quad \forall y, y' \subset \{X_{y's}^{TH} > 0, y > y'\} \quad (9)$$

For decision variables related to the marginal cost of new thermal investments, dynamic dependency constraints must be considered so that this conception is presented in constraint (9). $X_{yy'n}^{WY}$ is available Capacity of new wind unit installed at bus n, in year y' . In the years after the construction in year y (MW).

$$0 \leq P_{yy'n,tw}^{WY} \leq X_{yy'n}^{WY} \quad \forall y, y' \subset \{X_{y'n}^W > 0, y > y'\} \quad (10)$$

Constraint (10) is related to power limitations for blocks of generation constraints of wind turbine units in next years.

$$\min \sum_i \sum P_{yitw}^{ES} CS_i^{ES} + \sum_s \sum P_{yStw}^{TH} CS_S^{TH} + \sum_s \sum P_{yy'stw}^{THY} CS_{Sy'}^{THY} \quad (11)$$

The objective function of second level issue to clear the market is represented by the minus social welfare in constraint (11).

$$\sum_i P_{yitw}^{ES} + \sum_s P_{yStw}^{TH} + \sum_{yy'n,tw} P_{yy'n,tw}^{WY} + \sum_{yy'stw} P_{yy'stw}^{THY} + P_{yntw}^W - \sum_m B_{nm}^{PU} S_b (\theta_{ytnw} - \theta_{ymtw}) = \sum_j d_{yjt看} : \lambda_{ntw} \quad (12)$$

Constraint (12) defines the power balance at each bus so that the related dual variables are as or market clearing prices.

$$0 \leq P_{yy'stw}^{THY} \leq X_{yy's}^{THY} \quad \forall y, y' \subset \{X_{y's}^{TH} > 0, y > y'\} \quad (13)$$

Power bounds for blocks of generation units are as other second level constraints. In second level problem, lossless DC model is used for the power flow through transmission lines. Constraint (13) is related to the power bounds for blocks of generation constraints of new BPU units in the next years.

B. Multi-Stage stochastic mathematical program with equilibrium constraints (MPEC)

Owing to the fact the second level problems are continuous and linear, they are convex; consequently, KKT conditions can be used as a means to convert the proposed bi-level model to one level problem (MPEC) [7]. This resulting model is nonlinear because of existence of nonlinearities terms in the objective function of first level and in complementarity conditions obtained by enforcing KKT conditions to second level. Therefore, linearization is used to convert this problem to MILP one. To find a linear term

$$\sum_n P_{n,tw}^W \lambda_{n,tw} + \sum_s P_{Stw}^{TH} \lambda_{n,tw} + \sum_i P_{yitw}^{ES} \lambda_{n,tw} + \sum_s \sum_{y'} P_{yy'stw}^{THY} \lambda_{n,tw}, \text{ the strong duality}$$

theorem and some of the KKT equalities is used. In addition, $0 \leq a \perp b \geq 0$ can be replaced by $a \geq 0, b \geq 0, a \leq \tau M, b \leq (1-\tau)M, \tau \in \{0,1\}$, where M is a large enough constant [7].

III. CASE STUDY

To validate the proposed model, IEEE 24-bus reliability test System is considered as case study as it is depicted in Fig. 1 [19].

A. IEEE 24-bus Reliability Test System description

The input data related to demands and power units are according to [26]. Buses 7, 9 as well as 10 are assumed as imminent sites for installation of the wind units whilst buses 10, 11 and 14 are envisaged as upcoming sites so as to construct new thermal units. The multi stage planning is undertaken for ten years so that annual demand growth as well as annual discount rate are considered to be 10% and 8.7%, respectively. In addition, 1500 million dollars are considered as budget to invest new units in multi stage planning. Also, capacity of wind units is accessible in discrete 50-MW blocks

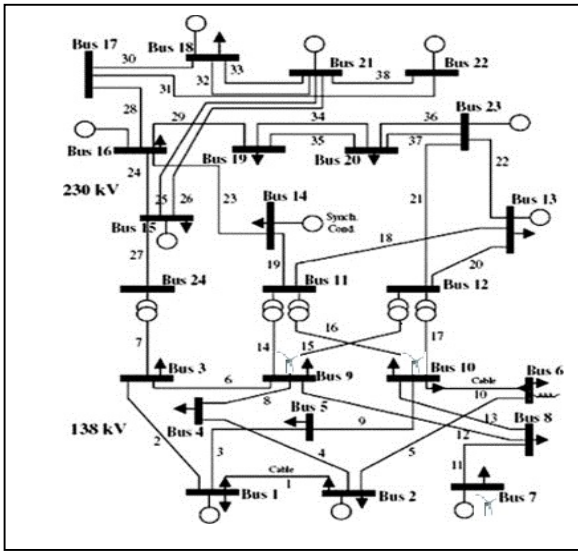


Fig. 1. IEEE 24-bus reliability test System [25]

Maximum capacities of wind units which can be constructed at buses 7, 9 and 10 are equal to 1000, 500 and 500 MW accordingly. Furthermore, base and peak technologies are considered as thermal units to invest. Base units includes high investment cost but small production cost whilst peak units have low investment cost but high production cost. Candidate capacity of base units are 0 and 500 MW. On the other hand, capacities 0, 200 and 250 are considered for investment in peak units. To solve this model, Solver XPRESS software GAMS is used. The Original problem has involves 1132783 rows, 1048522 cols, 2368893 elements and 351620 global. In addition, the resolved problem has involves 50476 rows, 80637 cols, 202927 elements and 490 global.

B. Result and Discussion

Table I presents the Results of the dynamic stochastic MPEC model for IEEE 24-bus Reliability Test System. The results of this case study are discussed as bellow:

In this market, the total capacity added by the producer in the planning horizon has been obtained equal to 3100 Mw so that producer invests 1600 MW in the wind technology and 1500 MW in the base technology. Also, distribution of the investment is as the below: 1450 MW on wind technology in the first year, 500 MW on base technology in the second year, 50 MW on wind technology in the fifth year, 500 MW on base technology in the sixth year, 50 MW on wind technology and 500 MW on base technology in the ninth year and 50 MW on wind technology in the tenth year of the planning period. Because the fact that offers of base units are less than offers of peak ones, total of new thermal constructions are based on base technologies. In addition, the total of WU and of BPU investments over the planning period are equal to 1159 M\$ and 340 M\$ accordingly.

It can be figured out that the production in the first year of planning period is 9147 MWh so that the production of wind, existing and base units is 3035 MWh, 6112 MWh and 0 MWh,

respectively. The production the new BPU production in the second year is 4024 MWh because of installation of 500 MW base technologies in bus 14 while the production of existing units decreases 44.36%. In second, third and fourth years, no wind units added to network and therefore, the wind production in these years is the same and equal to 3052 MWh. In these years, the total capacity of wind units is used for the production because this technology has no generating cost. The wind unit production in the fifth year increases 3.28% compared with the fourth year as a result of construction of 50 MW wind unit in bus 9. The production of new BPU in the sixth year has been increased by 92.04% compared to the fifth year in view of construction of 500 MW base unit in bus 11 and therefore the production of existing units decreases 36.45%. In the two next years, the production of the existing units has been increased by 34.45% and 29.93% compared to the sixth year, respectively, as a result of demand growth and no investment in wind or thermal technologies in these years. The production of wind and of new thermal units has been increased by 3.1% and 45.29% in the ninth year compared to the eighth year, respectively in view of installation of 500 MW base unit in bus 14 and of 50 MW wind technologies in bus 7. In the last year, the production of the existing, WU and new BPU is obtained 6889MWh, 3352 MWh, and 1256 MWh, respectively.

In the each year of planning, the market price increases due to demand growth so that 75.177 (\$/MWh) is obtained for the average market price. In addition, the total profit of the investor in the dynamic approach have been calculated 483.38 M\$.

• Impact of the Available Budget on the Investment

Table II shows the invested capacity in planning duration (ICIPD) and available capacity in planning duration (ACIPD) for WU and BPU in terms of available budget. ICIPD and ACIPD for new BPU have been obtained equal to 1500 MW and 3000 MW for the available budget 150 m\$, respectively. For calculate ACIPD must be noted that the unit is added to the network in the sixth year, can be used for 5 years. Therefore, for ACIPD of the new BPU, the amount of $5 \times 500 + 2 \times 500 + 1 \times 500$ is equal to 3000 MW in this available budget. ICIPD and ACIPD increase by increasing in the budget from 15 M\$ to the 1800 M\$. ICIPD in the budget 2400 M\$ is same as the budget 1800 M\$ while ACIPD have been increased by 500 MW. ICIPD and ACIPD for the budget 3000 M\$ is same as the budget 2400 M\$ and equal to 3250Mw and 26350, respectively. It can be seen increase in budget have no effect on ICIPD and ACIPD in large budget. Ina addition, Increase of ACIPD means that the more capacity is quickly added to the network.

Decrease in the budget cause the delay in investment. Investment in WU increases by increasing in the budget when the 1500 MW BPU have been added to the network. Therefore, it influence on the time of investment in BPU. In addition, the net profit increases by increasing in the budget. Furthermore, increase in budget has no effect on the net profit in large budget.

• Impact of the subsidy percent on the Investment

TABLE I. RESULTS OF THE GENERATION EXPANSION PLANNING FOR IEEE 24-BUS RELIABILITY TEST SYSTEM

Year	1	2	3	4	5	6	7	8	9	10	Total
Invested capacity (MW)	1450	500	0	0	50	500	0	0	550	50	3100
Wind investment (MW)	1450 (7-9-10)	0	0	0	50 (7)	0	0	0	50 (7)	50 (7)	1600
Base investment (MW)	0	500(14)	0	0	0	500(11)	0	0	500(14)	0	1500
Peak investment (MW)	0	0	0	0	0	0	0	0	0	0	0
Wind production (MMWh)	3.035	3.051	3.052	3.052	3.152	3.155	3.157	3.158	3.256	3.352	31.42
Existing generation(MMWh)	6.11	3.09	4.14	5.31	6.53	4.15	5.58	7.25	5.14	6.88	54.2
New BPU production (MMWh)	0	4.024	4.12	4.2	4.27	8.2	8.36	8.5	12.35	12.56	54.2
Wind Investment (M\$)	160.08	147.27	135.49	124.65	118.63	109.14	100.41	92.38	87.82	183.40	1159.293
BPU Investment (M\$)	0	31.17	29.2	26.86	24.71	45.476	41.838	38.49	53.12	48.87	340.31
Net profit (M\$)	40.89	45.24	45.22	45.05	45.31	49.2	49.98	50.51	54.91	57.06	483.38
Average price (\$/MWh)	72.683	73.084	73.779	74.341	74.674	75.131	75.54	76.361	77.523	78.655	75.177

TABLE II. THE SENSITIVITY OF ICIPD AND ACIPD FOR INVESTED UNITS IN TERMS OF AVAILABLE BUDGET .

Budget	ICIPD (MW)			ACIPD (MW)		
	WU	BPU	Total	WU	BPU	Total
15	100	0	100	300	0	300
150	50	1500	1550	50	3000	3050
600	350	1500	1850	2600	9000	11600
900	1050	1500	2550	7850	8000	15850
1200	1200	1500	2700	11350	7500	18850
1800	1750	1500	3250	16300	9500	25850
2400	1750	1500	3250	16350	10000	26350
3000	1750	1500	3250	16350	10000	26350

TABLE III. THE SENSITIVITY OF ICIPD AND ACIPD FOR INVESTED UNITS IN TERMS OF SUBSIDY PERCENT

Subsidy percent	ICIPD (MW)			ACIPD (MW)		
	WU	BPU	Total	WU	BPU	Total
0.05	400	1500	1900	2750	9500	12250
0.1	1250	1500	2750	5350	6000	11350
0.15	850	1500	2350	6700	4500	11100
0.2	1450	1000	2450	9500	2500	12000
0.25	1400	500	1900	9700	1000	10700
0.3	1500	0	1500	11900	0	11900
0.4	1500	0	1500	13400	0	13400
0.5	1700	0	1700	15500	0	15500
0.6	1850	1000	2850	17150	2000	19150
0.7	2000	1000	3000	20000	3500	23500
1	2000	1500	3500	20000	9500	29500

Table III shows the sensitivity of ICIPD and ACIPD for invested units in terms of subsidy percent. It was observed that ACIPD of WU have been increased by increasing subsidy percent while ICIPD of WU may be decreased. The maximum of ICIPD and ACIPD for WU is 2000 MW and 20000 MW, respectively. The time of investment in BPU are affected by increasing subsidy percent and therefore increase in ACIPD of wind units. At the first, ACIPD of new BPU have been decreased when subsidy percent increased from 0 to 0.3. Then, ACIPD of new BPU units have been increased from subsidy percent 0.5. In addition, The more investment in wind units occurs in the earlier years when amount of the subsidy percent is increased. Total capacity of wind units have been invested in first year of planning for subsidies percent 0.7 and 1.

- Impact of the demand on the Investment

Table IV shows the sensitivity of ICIPD and ACIPD for invested units in terms of demand consumption. The capacity of transmission lines are assumed to 3fmax in this case. . ICIPD and ACIPD of new thermal units increase by increasing demand consumption while ACIPD of wind units decreases in planning duration. Figure 8 and 9 depict the investment in wind and thermal units in the planning duration in terms of the demand consumption, respectively.

TABLE IV. THE SENSITIVITY OF ICIPD AND ACIPD FOR INVESTED UNITS IN TERMS OF DEMAND CONSUMPTION

Load factor	ICIPD (MW)			ACIPD (MW)		
	WU	BPU	Total	WU	BPU	Total
0.6	2000	500	2500	18700	2000	20700
0.8	1900	1000	2900	16700	5500	22200
1	2000	1500	3500	16000	7000	23000
1.2	1450	2000	3450	13400	11500	14900
1.4	1500	2500	4000	11700	13500	25200
1.6	1950	3000	4950	9950	17500	25550

Figure 2 shows changes in the production of units in terms of the demand consumption. It can be seen that the production of wind units decreases by increasing in demand consumption and decreasing in ACIPD of wind units while that the production of existing and new BPU increases in the planning duration. New BPU have more production in demand, supply by increasing the demand consumption due to their less operating cost with respect to the existing units and their less investment cost compared with the WU.

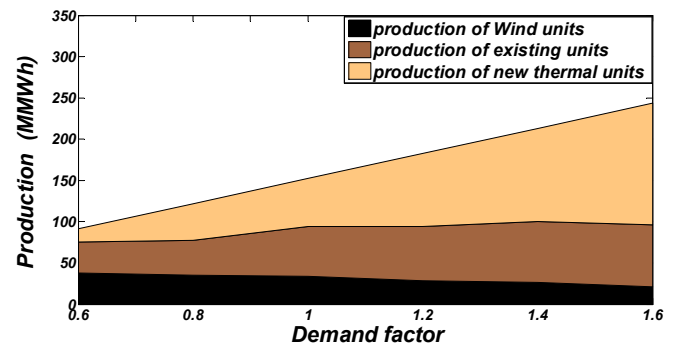


Fig. 2. Changes in the production of units in terms of the demand consumption.

IV. CONCLUSION

This paper presents a dynamic stochastic MPEC model for the expansion planning of Wind resources and BPU in power network at a multi-stage horizon. In this paper, the power system consists of a combination of fossil fuels technologies and Wind resources for investment. IEEE 24-bus Reliability Test System have been considered for case study and analyzed. According to simulations results as well as characteristics of the proposed model, the following conclusions can be obtained:

- Total invested capacity in planning duration (ICIPD) and total available capacity in planning duration (ACIPD) increase by increasing available budget. Furthermore, Decrease in the budget cause the delay in investment. Also, investment in wind units influence on the time of investment in thermal units. It can be seen that the net profit increases by increasing in the budget.
- It was observed that ACIPD of WU have been increased by increasing subsidy percent while ICIPD of WU may be decreased. The time of investment in BPU are affected by increasing subsidy percent and therefore increase in ACIPD of WU. Also, it can be seen that the more investment in WU occurs in the earlier years when amount of the subsidy percent is increased.
- ICIPD and ACIPD of new BPU increase by increasing demand consumption while ACIPD of WU decreases in planning duration. It can be seen that the production of WU decreases by increasing in demand consumption and decreasing in ACIPD of WU while that the production of existing and new BPU increases in the planning duration. New BPU have more production in demand supply by increasing the demand consumption due to their less operating cost with respect to the existing units and their less investment cost compared with the WU.

REFERENCES

- [1] M. Tavakoli, F. Shokridehaki, M. Marzband, R. Godina, and E. Pouresmaeil, "A two stage hierarchical control approach for the optimal energy management in commercial building microgrids based on local wind power and PEVs," *Sustainable Cities and Society*, Vol.41, pp. 332-340, August. 2018.
- [2] M. Marzband, M.H. Fouladfar, M.F. Akorede, and G. Lightbody, E. Pouresmaeil, "Framework for Smart Transactive Energy in Home-Microgrids Considering Coalition Formation and Demand Side Management," *Sustainable Cities and Society*, Vol.40, pp. 136-154, July. 2018.
- [3] J. Momoh, L. Mili, "Economic Market Design and Planning for Electric Power Systems," USA, NY, New York:Wiley-IEEE Press, Nov. 2009.
- [4] M. Marzband, F. Azarinejadian, M. Savaghebi, E. Pouresmaeil, J.M. Guerrero, and G. Lightbody, "Smart transactive energy framework in grid-connected multiple home microgrids under independent and coalition operations," *Renewable Energy*, Vol.126, pp. 95-106, October. 2018.
- [5] M. Tavakoli, F. Shokridehaki, M.F. Akorede, M. Marzband, I. Vechiu, and E. Pouresmaeil, "CVaR-based energy management scheme for optimal resilience and operational cost in commercial building microgrids," *Electrical Power and Energy Systems*, Vol.100, pp. 1-9, September. 2018.
- [6] M. Marzband, M. Javadi, S.A. Pourmousavi, and G. Lightbody, "An Advance Retail Electricity Market for Active Distribution Systems and home Microgrid Interoperability Based on Game Theory," *Electric Power Systems Research*, Vol.157, pp. 187-199, April. 2018.
- [7] M. Marzband, A. Sumper, J.L. Domínguez-García, R. Gumara-Ferret, "Experimental Validation of a Real Time Energy Management System for Microgrids in Islanded Mode Using a Local Day-Ahead Electricity Market and MINLP," *Energy Conversion and Management*, Vol.76, pp. 314-322, December. 2013.
- [8] L. Baringo, A. J. Conejo, "Wind Power Investment: A Benders Decomposition Approach," *IEEE Trans. Power Syst*, Vol. 27, No. 1, Feb 2012.
- [9] L. Baringo, A. J. Conejo, "Correlated wind-power production and electric load scenarios for investment decisions," *Applied Energy*, Vol.101, pp.475-482, June. 2013.
- [10] R. Girard, K. Laquaine, G. Kariniotakis, "Assessment of wind power predictability as a decision factor in the investment phase of wind farms," *Applied Energy*, Vol.101, pp. 609-617, June. 2012.
- [11] M. Gillenwater, "Probabilistic decision model of wind power investment and influence of green power market," *Energy Policy*, Vol.63, pp. 1111-1125, September. 2013.
- [12] L. Baringo, A.J. Conejo, "Risk-Constrained Multi-Stage Wind Power Investment," *IEEE Trans. Power Syst.*, vol. 8, no. 1, pp. 401-411, February. 2013.
- [13] J. Valinejad, M. Marzband, M. F. Akorede, T. Barforoshi, and M. Jovanovic, "Generation expansion planning in electricity market considering uncertainty in load demand and presence of strategic genscos," *Electric Power Systems Research*, vol. 152, pp. 92-104, 2017.
- [14] T. Barforoushi, M. P. Moghaddam, M. H. Javidi, and M. K. Sheikh-El-Eslami, "Evaluation of Regulatory Impacts on Dynamic Behavior of Investments in Electricity Markets: A New Hybrid DP/GAME Framework," *IEEE Trans. Power Syst*, Vol. 25, No. 4, Nov 2010.
- [15] A. Ghaderi, M. Parsa Moghaddam, M.K. Sheikh-El-Eslami, "Energy efficiency resource modeling in generation expansion planning," *Energy*, Vol.68, pp. 529-537, February. 2014.
- [16] J. Valinejad, Z. Oladi, T. Barforoshi, and M. Parvania, "Stochastic unit commitment in the presence of demand response program under uncertainties," *IJE TRANSACTIONS B: Applications*, vol. 30, no. 8, 671 pp. 1134-1143, August 2017.
- [17] S. Pineda, J.M. Morales, Y. Ding, J. Østergaard, "Impact of equipment failures and wind correlation on generation expansion planning," *Electric Power Systems Research*, Vol.116, pp. 451-458, June. 2014.
- [18] J. Valinejad and T. Barforoushi, "Generation expansion planning in electricity markets: A novel framework based on dynamic stochastic MPEC," *Elsevier*, *Electrical Power and Energy Systems*, Vol.70, pp. 108-117, Feb. 2015.
- [19] R. A. Jabr, "Robust Transmission Network Expansion Planning With Uncertain Renewable Generation and Loads," *IEEE Trans. Power Syst*, Vol. 28, No. 4, pp. 4558-4567, Nov 2013.
- [20] P. M. Artigues, P. D. Rio, "Combining tariffs, investment subsidies and soft loans in a renewable electricity deployment policy," *Energy Policy*, Vol.69, pp. 430-442, Jun. 2014.
- [21] M. Doyle, "Informational externalities, strategic delay, and optimal investment subsidies," *Canadian Journal of Economics*, Vol. 43, No. 3, pp. 941-966, Aug 2010.
- [22] F. Facchinei, J.S. Pang, "Finite dimensional Variational inequalities and complementarity problems," vol. 1, Springer-Verlag; 2003.
- [23] A.F. Hobbs, C. B. Metzler, J. S. Pang, "Calculating equilibria in imperfectly competitive power markets: an MPEC approach," *IEEE Trans Power Syst*, Vol. 15, No. 2, pp. 638-645, 2000.
- [24] J. Fortuny-Amat, B. A. McCarl, "representation and economic interpretation of a two-level programming problem," *Oper Res*, Vol. 32, No. 9, pp. 783-792, 1981.
- [25] Reliability Test System Task Force, "The IEEE reliability test system-1996," *IEEE Trans. Power Syst*, Vol. 14, no.3, pp. 1010 - 1020, Aug. 1999.
- [26] L. Baringo, A.J. Conejo, "Wind power investment within a market environment," *Applied Energy*, Vol.88, pp.3239-3247, March. 2011.